A HIGH EFFICIENCY LONG PULSE MULTI BEAM KLYSTRON FOR THE TESLA LINEAR COLLIDER

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Abstract

The Tesla linear collider requires 600 pieces of 10MW L-Band klystrons operating at a pulse duration of 1.5ms and a repetition rate of up to 10Hz with an efficiency of the order of 70%. Since these performances are not achievable with a single beam klystron, a multi beam klystron (MBK), which uses many low perveance electron beams in parallel in one vacuum envelope, was developed by THOMSON TUBES ELECTRONIQUES (TTE). The advantage of this solution is the low voltage required and the high efficiency compared with a single beam klystron. THOMSON TTE has developed and manufactured the TH1801. This MBK is in operation at the Tesla Test Facility at DESY, where it was tested at full pulse duration of 1.5ms. It reached 10MW at 117kV and 131A with an efficiency of 65%. This paper reports on the tubes, the test results and the operation experience of the TH1801 multi beam klystrons built until now.

1 THE TESLA LINEAR COLLIDER

The TESLA Linear Collider is a 500 to 800 GeV_{cm} e+/e- linear collider with integrated Free Electron Laser (FEL) facility. The electrons and positrons are accelerated in two ~15km long opposing linacs using ~10000 superconducting 1.3GHz 9-cell cavities per linac. The accelerating gradient is 23.4MV/m for the 500GeV and 35MV/m for the 800GeV collider respectively. In the following we will restrict ourselves on the parameters of the 500GeV collider.

The macro beam pulse consisting of 2820 bunches with a spacing 337ns has a duration of 950µs. The collider is operated with a beam pulse repetition rate of 5Hz with the exception of about 3km of the electron linac operating at 10Hz, where every second pulse is used for FEL operation. In order to achieve the accelerating gradient of 23.4MV/m at a beam current of 9.5mA 231kW of RF input power per cavity are required. Additional power of 6% must be foreseen for waveguide losses and another 10% as regulation reserve. The RF pulse duration of 1.37ms is given as the sum of the beam pulse duration of 950µs and the cavity filling time of 420µs. More detailed information can be found in [1].

2 RF SOURCE REQUIREMENTS

In order to minimize the cost of the entire RF system and in order to achieve high reliability the number of RF stations, which convert AC line power into RF power for the superconducting cavities, and hence the number of RF sources should be chosen as small as possible. The RF power generated by each RF source must then be distributed to a number of cavities. This results in the demand of the highest output power, which can be generated reliably by one RF source.

Some years ago the THOMSON TH2104 was the klystron with the highest output power at long pulse duration at 1.3GHz. 5MW could be generated with this klystron. About 1200 klystrons of this type would be required to equip the TESLA collider. In case of doubling the output power from 5MW to 10MW the number of klystrons could be reduced to about 600 each supplying RF power to 36 superconducting cavities.

Besides cost and reliability, efficiency is another important item, since the power demand of the RF sources determines to a big extent the power demand of the entire collider.

One of the parameters which determines the efficiency of a klystron is the perveance defined as $p=I/U^{3/2}$, where U is the klystron cathode voltage and I the klystron current. Comparison of various klystrons shows that the klystron efficiency increases with lower perveance [2, 3]. For a perveance of $2.0\cdot10^{-6}A/V^{3/2}$ the efficiency typically is 45%, whereas at $0.5\cdot10^{-6}A/V^{3/2}$ 70% seems to be feasible. The increase in efficiency is due to the effect that a low perveance results in a low space charge density which allows easier bunching and therefore better energy transfer from the DC to the AC component of the klystron electron beam.

The TH2104 has an RF output power of 5MW at a voltage of 128kV and a current of 88A, hence the perveance is $1.92\cdot10^{-6}A/V^{3/2}$ and the efficiency 44%.

The attempt to construct a klystron with an efficiency of 70% and an output power of 10MW based on a single klystron electron beam with a perveance of $0.5\cdot10^{-6}$ $A/V^{3/2}$ would result in a klystron beam voltage of 241kV. Since the required pulse duration is 1.5ms the construction of a klystron meeting these parameters seems to be impossible.

The solution is the use of several low perveance beams in parallel at lower voltage in one vacuum vessel. This technology is utilized in the multi beam klystron.

3 THE TH1801

THOMSON TUBES ELECTRONIQUES has developed and built the TH1801, a long pulse high efficiency multi beam klystron [4]. It uses seven electron beams in parallel, which are produced by the klystron cathode shown in figure 1.

Figure 1: Cathode of the TH1801

The perveance per beam is $0.5 \cdot 10^{-6} A/V^{3/2}$. The klystron has 6 cavities including input and output cavity. The beams share the cavities but have independent drift tubes. After RF extraction in the output cavity the spent beams are absorbed in the collector. Two output waveguides of type WR650 with two pillbox windows are used to handle the output power of two times 5MW at 1.5ms pulse duration. Figure 2 shows the TH1801 without electromagnet. The total height is ~2.5m.

Figure 2: The TH1801 multi beam klystron

The design parameters are summarized in table 1. The design cathode voltage of 110kV is lower than the cathode voltage required for the TH2104 5MW klystron, thus allowing the installation of a 10MW MBK in the same modulator only requiring slight modifications for the higher klystron current and for a different filament power. The 10MW tube requires only ~360W of filament power instead of ~560W required for the 5MW tubes.

Table 1: Design parameters of the TH1801

	Design
Operation Frequency	1300MHz
RF Pulse Duration	1.5ms
Repetition Rate	10Hz
Cathode Voltage	110kV
Beam Current	130A
HV Pulse Duration	1.7ms
No. of Beams	7
Total Perveance	$3.5 \cdot 10^{-6}$ $A/V^{3/2}$
No. of Cavities	6
Max. RF Peak Power	10MW
RF Average Power	150kW
Efficiency	70% goal
Gain	48dB
Solenoid Power	4kW goal

4 TEST RESULTS

Two MBKs have been produced until the end of 2000. Both have completed the factory acceptance test at THOMSON, where they were tested to full RF power at shorter pulse duration of 0.5ms but higher repetition rate of 30Hz, since no modulator for a pulse duration of more than 0.5ms exists at THOMSON. The first klystron was installed in May 2000 in one of the HV modulators at the TESLA Test Facility (TTF) at DESY and then conditioned and tested to full RF power at full pulse width of 1.5ms, but lower repetition rate of 5Hz. It is now in use for the operation of TTF. The second MBK will be tested at full pulse duration in one of the new HV modulators now being installed at DESY.

Figure 3 shows output power of the first MBK as function of the input power for various beam voltages, pulse durations and operation conditions. The RF output power was determined from calorimetric data taken from RF loads. The measurements at 0.5ms performed at THOMSON and at 1.5ms performed at DESY respectively are in good agreement for the same voltages. The measurements were done using water loads at THOMSON and water cooled ferrite loads at DESY under matched load conditions with a VSWR smaller than 1.1. These measurements are indicated as Mode A. Additional measurements with mismatched water loads with a VSWR of 1.2 at optimum phase conditions were performed at THOMSON, indicated as Mode B. Under these conditions the RF output power is higher than for perfectly matched load conditions. The efficiency using matched loads is 65%, whereas with mismatched loads an efficiency of 68% could be achieved at 117kV.

The high gain of 48dB allows the use of semiconductor drive amplifiers. Figure 4 shows the waveforms recorded during the test at DESY. The perveance of $3.27 \cdot 10^{-6} A/V^{3/2}$ is lower than design, thus together with the slightly lower efficiency leading to higher beam voltages. This klystron was operated at 5Hz repetition rate to full power under all conditions. At 10Hz we were restricted to 105kV operation voltage or 7MW output power respectively, because of main power limitations.

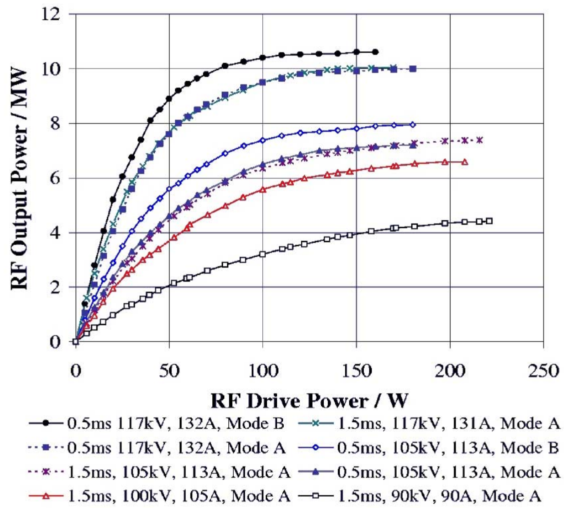

Figure 3: RF output power as function of RF drive power of the first MBK for different operation conditions

The 1dB bandwidth is more than ±5MHz. We also measured a phase sensitivity of this klystron of 14.3°/kV.

After completion of the site acceptance test the first MBK became one of the klystrons used for TTF operation. Since only 16 superconducting cavities are connected, the klystron is operated at less than 5MW of total RF output power, typically at 3 to 4MW.

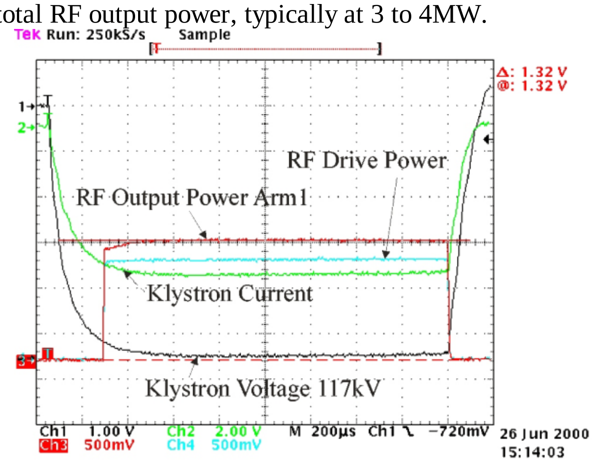

Figure 4: Waveforms at 10MW output power recorded at the first MBK during the long pulse test at DESY

The test results of the second MBK at 0.5ms pulse duration are shown in figure 5. The maximum efficiency of 63% for Mode A and 66% for Mode B at 116kV is slightly lower than for the first klystron. This is due to a detuning of +4MHz of the output cavity, which occurred during tube bakeout. Moreover, the output cavity had a low Q_x. Measures to avoid this will be taken for the next MBKs. The perveance of $3.44 \cdot 10^{-6} A/V^{3/2}$ is close to the design perveance.

Both MBKs require a slightly higher solenoid power of 5.5kW than the design goal of 4kW.

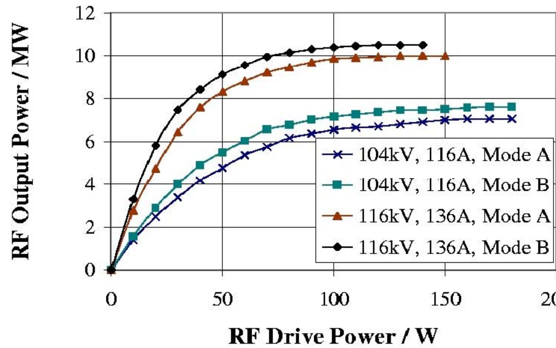

Figure 5: RF output power as function of RF drive power of the second MBK at 0.5ms pulse duration for different operation conditions

5 SUMMARY

THOMSON TTE has successfully developed and built a long pulse high efficiency multi beam klystron. All tubes, which have been built and tested up to now, are close to the design goals. Additional tubes and further testing at long pulse duration is required and will be done at TTF at DESY, where these klystrons will be installed and used for the operation of TTF. For the TESLA linear collider additional modifications are required, in order to meet the infrastructure requirements of the tunnel installation, for instance the horizontal mounting position.

6 ACKNOWLEDGEMENTS

The authors would like to acknowledge the work of T. Böckmann, T. Grevsmühl, J. Kahl, F.-R. Kaiser, V. Katelev, F. Lu, G. Möller, S. Simrock, I. Sokolov, H. Timm and U. Zobjack during the installation and testing of the first MBK at DESY.

REFERENCES

[1] R. Brinkmann, “TESLA Linear Collider Design and R&D Status”, Proceedings of the XX International Linac Conference, LINAC2000, Monterey, USA, August 21-25, 2000

[2] C. Bearzatto, M. Bres, G. Faillon, “Advantages of Multiple Beam Klystrons”, ITG Garmisch-Partenkirchen, Germany, May 4 -5, 1992

[3] R. Palmer, “Introduction to Cluster Klystrons”, Proceedings of the International Workshop on Pulsed RF Power Sources For Linear Colliders, RF93, Dubna, Protvino, Russia, July 5-9,1993

[4] A. Beunas, G. Faillon, “10 MW/1.5 ms, L-band multi-beam klystron”, Proc. Conf. Displays and Vacuum Electronics, Garmisch-Partenkirchen, Germany, April 29-30, 1998